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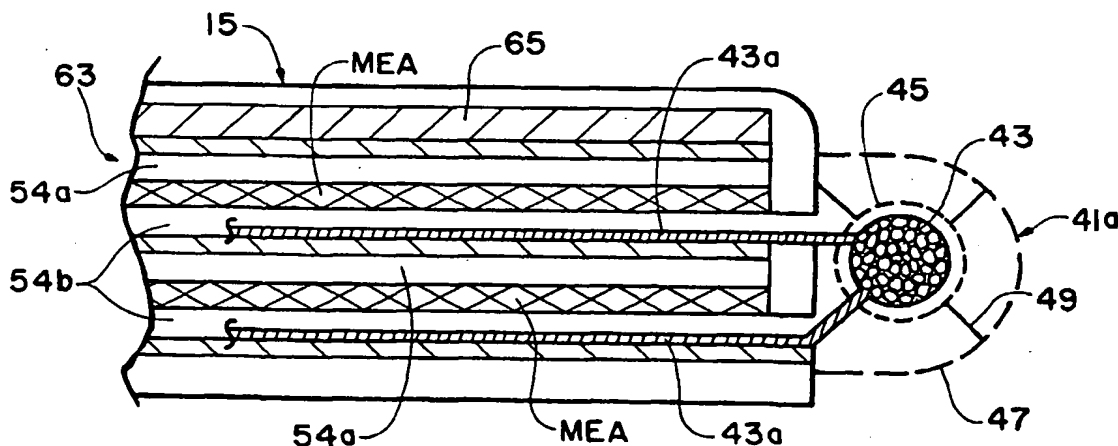
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(54) Title: PORTABLE ELECTRONIC DEVICE POWERED BY PROTON EXCHANGE MEMBRANE FUEL CELL



(57) Abstract: A portable electronic device (11) incorporates PEM fuel cells (33) and is designed to operate by the reaction of hydrogen from a hydride-containing fuel container (27) and oxygen from the air, while efficiently removing the product water by a novel water transportation system (41). Temperature is effectively controlled within a laptop PC by locating a plurality of fuel cell subunits as a generally planar array in the lid (15) of the PC adjacent a heat transfer plate (65). A particularly efficient resupply system is provided where an electrolyzer (71) supplies H<sub>2</sub> at a pressure sufficient to continue to power the PC and simultaneously recharge an operatively-connected main hydride reservoir (27) and a second spare hydride reservoir (27) in the electrolyzer, each of which reservoirs has an associated reserve container (91).

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## **PORTABLE ELECTRONIC DEVICE POWERED BY PROTON EXCHANGE MEMBRANE FUEL CELL**

### **Field of the Invention**

This invention relates to portable electronic devices powered by proton exchange membrane (PEM) fuel cells which produce water as a by-product of electricity generation. More specifically, the invention relates to portable electronic devices, such as laptop computers and the like, as well as handheld computers and cellular telephones, but offers particular advantages for devices which employ a two-piece case and that are powered by PEM fuel cells, and in addition relates to associated units for recharging such fuel cells.

### **Background of the Invention**

PEMs are a type of fuel cell wherein a chemical reaction occurs between hydrogen and oxygen converting chemical energy directly into electrical energy and efficiently generating power while the only by-product is water. Hydrogen for such fuel cells can be supplied from a variety of known sources. PEM fuel cells are well known, and such cells which use hydrogen and air to create electricity are shown, for example, in U.S. Patent No. 5,776,625. Such fuel cells are commercially available from DeNora S.p.A. Atmospheric air is a readily available source for oxygen, and hydrogen is conveniently supplied from tanks loaded with granular metal alloys which store hydrogen as in the form of a hydride. Such hydrogen storage units are disclosed, for example, in U.S. Patent Nos. 4,489,205, 5,512,145, 5,314,762, 5,976,725 and 6,057,051.

Certain of these patents disclose the incorporation of fuel cells of this general type in laptop personal computers (PCs). However, as of yet, these devices have been generally conceptual, and it has been felt that improvements in such systems are necessary before they will obtain widespread commercial acceptance. Accordingly, the industry has continued to pursue such improvements.

### **Summary of the Invention**

The invention provides portable electronic devices powered by PEM fuel cells which include arrangements for effectively and efficiently removing water generated at such fuel cells from the interior of a case, such as a case which holds the commonly used laptop personal computer.

The invention further provides a combination of such a PEM fuel cell-powered portable electronic device with an electrolyzer unit for efficiently recharging a hydrogen reservoir while at the same time powering the electronic device.

The invention also provides a portable personal computer which is powered by a PEM fuel cell that is incorporated within a two-piece case having the central processing unit (CPU) in the base of the case and the display screen in the lid of the case, where air entering the base of the case is blown past the CPU, channeled to the lid and then leaves the case through exit openings in the lid after supplying oxygen to the PEM fuel cells that are located in the lid behind the display screen and removing heat therefrom.

In one particular aspect, the invention provides a portable electronic device which is powered by a proton exchange membrane (PEM) fuel cell that produces water as a by-product of electricity generation, which device comprises a case, an electronic unit and a display screen in the case, a fuel cell in said case for providing electric power which creates water as a by-product, said case containing air entrance and exit openings to the exterior, and a hydrophilic water transporter for transferring said by-product water away from said fuel cell, which water transporter is located along a perimeter boundary of the case, said water transporter including a perforated outer generally tubular holder which is associated with the exit opening and a generally coaxial perforated inner tube of lesser diameter with elongated hydrophilic wick material disposed within the inner tube, whereby said water transporter adsorbs water in the vicinity of the fuel cell and adsorbed water is distributed along and throughout the hydrophilic wick, aiding its evaporation into air in the annular region between the perforated inner and outer tubes, and subsequently exits from the case as water vapor via the exit opening.

In another particular aspect, the invention provides a portable electronic device which is powered by a proton exchange membrane (PEM) fuel cell in combination with an electrolyzer unit for recharging a hydrogen reservoir, which combination comprises (a) an electronic device disposed within a carrying case along with a fuel cell, a first hydrogen reservoir and a conduit arrangement interconnecting the hydrogen reservoir and fuel cell, said conduit arrangement includes a line leading to a recharging connector which transverses a wall of the case, said hydrogen reservoir being detachably connected to the conduit arrangement to permit its optional removal and replacement, and (b) an electrolyzer unit including means for generating hydrogen gas and supplying generated gas (i) to a second hydrogen reservoir detachably connected to the electrolyzer unit and (ii) to flexible tubing for connection to the conduit arrangement and therethrough to both

the fuel cell and to the first hydrogen reservoir, whereby the electrolyzer can supply hydrogen gas to power the device while simultaneously recharging the first and second reservoirs.

In a further particulate aspect, the invention provides a portable personal computer (PC) which is powered by a proton exchange membrane (PEM) fuel cell that produces water as a by-product of electricity generation, which device comprises a two-piece case, a CPU in a first piece of said case, a display screen in a second piece of the case, hinge means interconnecting the two case pieces, a fuel cell for providing electric power which creates water as a by-product in the second piece of the case, circulatory means residing in the first piece of the case for supplying air to the fuel cell, said fuel cell being electrically connected to the CPU through the hinge, said first case piece being formed with air entrance means and said second case piece being formed with air exit means, and passageway means extending through the hinge and interconnecting the interiors of the two case pieces, so that air carrying heat from the CPU flows through the passageway means and then through the PEM fuel cell, providing oxygen thereto, taking up by-product water as vapor, and carrying water vapor exterior of the second case piece through the air exit.

#### **Brief Description of the Drawings**

FIG. 1 is a schematic view showing a portable electronic device in the form of a personal laptop computer which incorporates a two-piece hinged case in combination with an electrolyzer unit which generates hydrogen gas for recharging purposes.

FIG. 2 is a schematic view of certain of the operating components located in the base compartment of the personal computer of FIG. 1.

FIG. 3 is a schematic view of certain of the fuel cell and water transportation system located in the lid compartment of the personal computer of FIG. 1, which shows how air and  $H_2$  are supplied to the PEM fuel cells.

FIG. 4 is a schematic side view of a portion of the operating system for removing product water from the PEM fuel cells.

FIG. 5 is a cross-sectional view taken generally along line 5-5 of FIG. 4.

FIG. 6 is a schematic view showing an alternative embodiment wherein multiple hydride containers are located in the base section of the laptop computer, shown with the compartment cover removed.

FIG. 7 is a schematic view showing the operation of a PEM fuel cell.

FIG. 8 is a perspective rear view of a PC schematically showing a water transportation system located along two side edges of the lid section.

FIG. 9 is an enlarged fragmentary diagrammatic view taken generally along the line 9-9 showing a side edge portion of the lid which illustrates the location of the wick system.

FIGS. 10, 11 and 12 are, respectively, top, cross-sectional and front views of a hydride container that might be employed in the computer of FIG. 1.

FIGS. 13 and 14 are a cross-sectional view and an end view of an alternative form of a hydride container.

FIG. 15 is a perspective view of the electrolyzer of FIG. 1 opened to show a hydride container in recharge position.

FIG. 16 is a schematic view, similar to FIG. 2 of an alternative embodiment of a personal laptop computer embodying various features of the invention.

FIG. 17 is a schematic view similar to FIG. 3 which shows an alternative arrangement for supplying air and hydrogen to PEM fuel cells in a laptop computer embodying various features of the invention.

#### **Detailed Description of the Preferred Embodiments**

This inventive concept revolves around the employment of PEM fuel cells. As shown schematically in FIG. 7, these proton exchange membrane fuel cells employ a polymer membrane as the electrolyte; although the membrane is an electronic insulator, it serves as an excellent conductor of hydrogen ions. Although various membranes can be used, a preferred membrane is that which is marketed by DuPont under the trademark Nafion, for a perfluorosulfonate monomer. Nafion is one example of one such polytetrafluoroethylene(Teflon)-based ionomer useful as an electrolyte in fuel cells; it is a perfluoronated polymer containing small proportions of sulfonic and/or carboxylic ionic functional groups.

Electrodes may be created by coating opposite surfaces of, for example, a planar membrane. Anodes and cathodes are prepared in a suitable manner, as known in this art; for example, they may be prepared by applying small amounts of platinum black to one surface of a thin sheet of porous graphitized paper that has been previously wet-proofed with Teflon. The Nafion electrolyte is then sandwiched between two such sheets, which serve as the anode and the cathode, and the three components are sealed together under heat and pressure to produce a single membrane/electrode assembly, sometimes referred to as an MEA. Alternatively, the membrane may be directly transformed into an MEA

by applying a solution/paste of Nafion monomer and platinum black to opposite surfaces of the membrane. In any instance, the MEA will usually be less than a millimeter in thickness. Platinum black serves as a catalyst at both the anode and the cathode in one such arrangement developed by the U.S. DOD. Other suitable catalysts may alternatively  
5 be used. The anode and cathode are respectively in contact, on the rear side of each, with flow field plates; for example, graphite or metal plates in which gas supply channels have been formed may be used. Examples of such plates are shown in U.S. Patent No. 5,952,118. The ridges between the adjacent channels make electrical contact with the  
10 respective electrode surfaces and supply current to an external circuit, while the channels supply hydrogen to the anode and oxygen (air) to the cathode.

Hydrogen is consumed at the anode yielding electrons to the anode and producing hydrogen ions which enter the electrolyte. The H<sub>2</sub> channels may be dead-ended as shown in FIGS. 3 and 9; however, it might be preferable to be able to periodically vent these channels as by employing an alternative construction discussed hereinafter. At the  
15 cathode, oxygen from the stream of air that is being supplied combines with electrons from the cathode and with hydrogen ion from the electrolyte producing water vapor. The major portion of the water vapor is rejected from the rear surface of the cathode where it creates a high humidity stream that is directed to an exit conduit, which stream is composed of the nitrogen content of the air and the portion of the oxygen that does not  
20 react. A PEM fuel cell operating with a Nafion membrane will likely operate at a temperature of about 50 to 80°C so that most of the water being formed will be in vapor form. Under certain circumstances, e.g. when operating at peak power and in a location where the ambient conditions may have an elevated humidity, some water vapor may condense to fine droplets in the oxygen flow channels. Preferably, the arrangement will  
25 be such that, when the computer is in its operating mode, the stream of air flowing through the cathode side of the MEA will exit horizontally, and the flowing stream of air will force any condensed water out of the oxygen channels of the MEA. Located adjacent the discharge from the air flow channels is a wick or water transportation arrangement, which is described in detail hereinafter; it effectively and efficiently carries  
30 any condensed water away from the immediate vicinity of the fuel cell, dispersing it along a large surface area which aids in evaporation and subsequent discharge from the portable electronic unit in the form of water vapor, so that no liquid water will drip from or be apparent on the exterior of the electronic device.

Illustrated in FIG. 1 is a personal computer 11 of the laptop type which includes a two-piece case wherein a lower or a base section 13 is hinged to an upper or lid section 15 by a pair of hinges 17a and 17b, which are preferably located at opposite ends of the rear wall of the base section although they could alternatively be provided in other  
5 locations if desired. The base section 13 of the computer includes a standard keyboard 19 in its upper surface, which covers the main compartment wherein operative elements of the PC reside.

As schematically depicted in FIG. 2, the compartment includes a CPU 21, a blower or fan 23 for circulating air past the CPU, electrical circuitry 25 (represented  
10 schematically), a hydrogen supply container or cartridge 27, preferably containing a bed of particulate metal alloy hydride 28, and a hydrogen gas conduit system 29. A display screen 31 is located in the undersurface of the lid section 15, and although liquid crystal displays (LCDs) are presently state-of-the-art, any suitable visual display device might be used, e.g. an LED, an OLED or a monochrome plasma display. As illustrated in FIG. 3,  
15 the PEM fuel cell power-generating unit 33 is preferably located in the compartment provided in the lid section 15 between the display screen 31 and the cover or wall surface 35 of the lid. The fuel cell unit 33 may alternatively be located with the CPU in the base section compartment, where it would of course be located in a one-piece device; however, its preferable location in an internal compartment within the lid section 15 of a  
20 two-piece device gives rise to particular advantages that are explained in detail hereinafter.

When the fuel cell unit 33 is located in the lid section, a DC/DC converter 37 may also be located there; for example, such a voltage converter may be located between two fuel cells and electrically connected to each as shown in EP 942,483 (15 Sept. 1999).  
25 Such an arrangement is shown in FIG. 17. Alternatively, as illustrated in FIG. 2, the DC/DC converter 37 is located in the base section adjacent to the CPU. Electrical connections between the components in the lid section and those in the base section are effected through sliding contacts in the hinge 17a, as generally well known in this art. In the illustrated embodiment, the electrical power from the fuel cell unit 33 flows through  
30 such an electrical connection in the hinge 17a to the DC/DC converter and then to the CPU which is part of a mainboard and to the peripheral circuitry 25 which supplies power to the blower motor 23; whereas, in the alternative and perhaps preferred embodiment mentioned above, it would flow through the voltage converter before passing through the hinge. Thereafter, the output signals from the mainboard flow back

through a second electrical connection in the hinge 17a to the display screen in the lid section. The peripheral circuitry 25 of course also interconnects the keyboard 19 and the CPU 21. This electrical circuitry also includes the usual connector and adaptor (not shown) for running the PC from standard, e.g. 120V AC, power.

5           The hydrogen container 27 is a replaceable item and is conveniently located in a compartment or pocket 39 provided in the base compartment 13. This arrangement may be a generally similar arrangement to many present day laptop computers where a battery-pack can be plugged in by insertion into a compartment that is accessible through a door or hatch in the bottom wall of the PC case. The hydrogen container 27 is a  
10 rechargeable item and is used whenever the user is not in a location where an electrical power source is available, for example on an airline or in some remote location. Similar to carrying a spare battery, a user simply carries a spare container that can be inserted after removal of the container that has become temporarily depleted of hydrogen. The details of the hydrogen container 27 and alternative versions thereof are discussed in  
15 detail hereinafter.

One feature of the invention is an unique system 41 for effectively removing the by-product water from the fuel cell unit 33; this system employs a wick arrangement as the key feature and is schematically depicted in FIGS. 4 and 5. A wick 43, i.e. a hydrophilic water transporter, in its preferred form is a braided or otherwise accumulated  
20 group of strands of polypropylene fiber or some other polymeric fiber that is either inherently hydrophilic or treated so as to have hydrophilic surface characteristics. Moreover, because it will be moist for potentially extended periods during operation and for some time thereafter, the wick is preferably treated with an antimicrobial agent, such as Triclosan, Oxeco or TCC, to combat mold and rot. The wick 43 is located adjacent  
25 the air outlet passages from the fuel cell unit(s) 33. As mentioned above, the fuel cells are preferably located in the lid compartment and will normally be vertically aligned, or nearly vertical, when the PC is in use. The MEAs will be oriented so that the O<sub>2</sub> flow channels are horizontal, and preferably at least the major portion of the wick 43 is located along a perimeter boundary of that section of the PC case containing the fuel cell unit 33,  
30 here the lid section 15, e.g. along one or both side edges of the lid.

In order to provide access to the surrounding air environment, the wick 43, which has a generally cylindrical shape, is disposed in a porous tube 45 that is positioned inside a generally coaxial porous outer tubular holder 47. This is shown schematically in FIGS. 4 and 5 wherein the wick is disposed in a central tube 45 of screen-like material and

cylindrical shape. The wick 43 is preferably slightly smaller in diameter, in its dry condition, than the interior diameter of the screen-like tube 45; however, once wet, it may swell to approximately fill the cylindrical cavity thereof. Because of the high porosity of the tube 45, i.e. preferably greater than 80% and more preferably greater than 90%, the surface of the wick 43 is always exposed to the ambient environment, thus promoting evaporation at its surface. The outer coaxial holder 47 is depicted as having a large number of circular holes so that it too is highly porous. Although the depiction is only diagrammatic, the porosity of the wall of the holder is preferably at least about 60% and more preferably at least about 80%, and it may be a lattice.

10 In order to uniformly space the wick 43 within the outer tubular holder 47, a plurality of radial arms or standoffs 49 are provided at regular intervals along the length of the coaxial tubes. These radial arms 49 can be fixed to either the exterior surface of the interior tube 45 or the interior surface of the outer perforated holder 47; they maintain the inner tube 45 (and thus the cylindrical wick itself) in substantially coaxial orientation within the outer holder. Generally, the air exiting from the O<sub>2</sub> flow channels will be at a slightly elevated temperature, for example between about 25° and about 35°C, and it will contain water vapor and perhaps some entrained water. These streams exiting from the horizontal channels in the fuel cell unit 33 will be flowing in a direction transverse, i.e. perpendicular, to the wick arrangement 41 which, as previously indicated, is preferably formed as two sections located in flanking arrangement along both edges of the lid. Assuming the case is made of molded polymeric material, the tubular holders 47 are preferably molded as integral parts of both side edges of the lid 15. The air streams exiting the fuel cells are directed radially into the annular passageway between the tube 45 and the holder 47, and the design may omit a longitudinal section of the holder 47 to provide a gap (see G in FIG. 5) which would be aligned with the edge of the fuel cell unit and through which the exiting air would pass. Because the air temperature will quickly drop toward ambient, whatever water vapor that may be released from the air will condense upon the tube 45 and the wick 43 where it will be transported along the entire length of the hydrophilic wick, as a result of which there will be no dripping and no condensation on the exterior surface of the case. The moisture created will be always able to evaporate into the air that is flowing outward and will carry the water, as humidity, exterior of the lid compartment through exit openings in its sidewall edges. Particularly efficient removal is achieved in the illustrated embodiment where there is constant interchange of ambient air with the air exiting from the fuel cells as a result of

making the holder 47, so as to have openings in its outer wall, which exposes the entire length of the wick to the ambient air. As described hereinafter, the wick 43 may optionally have individual strands 43a that are disposed in the air passageways in the cathode supply plate to collect any water that might condense therein.

5           The movement of air into the fuel cell unit(s) 33 may be provided by the blower 23 in the base compartment which takes its suction from an adjacent entrance opening in one vertical sidewall of the base compartment and directs the air past the CPU 21 to cool it and maintain it and other components in the base at optimum operating temperatures. When the blower 23 is used for this function, it may be connected by a conduit to a  
10           sidewall air entrance opening into the substantially sealed base compartment so as to create an overpressure throughout the remainder of the base compartment. Alternatively, it might be funneled into a passageway inlet and provided with baffling to take its suction from the vicinity of the CPU.

          In any event, air leaves the base compartment through an interconnecting  
15           passageway system provided in the hinge 17b. While the blower is running, it causes a continuous stream of air to leave the base compartment and flow through the hinge passageway system where it enters a conduit arrangement 51 (FIG. 3) that directs the air to the feed side of the fuel cell unit 33 (to the feed sides of each of a plurality of fuel cell subunits when more than one stack of fuel cells is employed). At each fuel cell unit or  
20           subunit, the stream of air is directed to a manifold 53b as generally depicted in the '118 patent, from which it then flows through a plurality of passageways or channels 54b provided adjacent the cathode surface of each MEA; similar channels 54a of a dead end variety are provided adjacent the anode surface thereof. If desired for design purposes, a separate blower or other air-moving device might be provided solely for O<sub>2</sub> supply. Such  
25           could likewise be located in the base compartment or might alternatively be located in the lid compartment if a flat profile device were used. In the alternative embodiment illustrated in FIG. 16 and described hereinafter, a positive displacement circulator or pump is used to supply air to fuel cells having a different gas supply passageway arrangement.

30           During its travel through the fuel cell unit 33, the air flowing in the parallel channels 54b is slightly depleted in oxygen where it picks up water vapor being created at the cathode and perhaps even some entrained microdroplets of water. In the embodiment shown in FIG. 2, a single blower 23 in the base compartment supplies not only the cooling for the CPU 21 in the base compartment but the oxygen for reaction at  
35           the fuel cells in the lid compartment while also carrying away heat (as well as moisture)

from the fuel cells so that they are maintained within a desired operating temperature range, e.g. of about 50° to about 80°C.

In the preferred embodiment, the wick arrangement 41 including the coaxial perforated tube and holder extends along both side edges of the lid compartment 15 of the PC, as depicted in FIGS. 8 and 9. Two wick sections 41a are located in parallel orientation, one along each of the two side edges of the lid compartment, where they flank the display screen 31. In this embodiment, two side-by-side fuel cell units 33a are used with the air being supplied centrally therebetween. Thus, small streams of air are traveling in opposite directions toward the side edges of the lid. In this arrangement, the streams of air deliver moisture generally along the entire length of each wick allowing moisture to condense thereupon and thereafter be transported throughout the hydrophilic material, slowly evaporating into the air streams as humidity conditions permit and traveling out through the ample openings in the sidewalls of the lid compartment to reach the ambient atmosphere.

From the standpoint of the wick arrangement, FIG. 9 shows the alternative embodiment that was briefly previously mentioned. Rather than simply relying upon the moving streams of air to carry moisture to the hydrophilic wick material 43, individual strands 43a of stranded wick material 43 are branched from the main cylindrical body of the wick and located near the bottoms of the flow passageways 54b that carry the air past the cathode surface of the MEA. This arrangement avoids the possibility that small water droplets might condense in various of the small parallel channels 54b that carry the air flow, with such water droplets creating a blockage that could potentially starve a small portion of the MEA adjacent any such channel of its oxygen fuel and slightly reduce power production in that fuel cell. However, by disposing a small strand 43a of hydrophilic fibers at the bottom of the air flow passageways 54b, if a droplet were to form and, through surface tension, have such a potentially undesirable blocking effect, the water would be quickly absorbed onto the hydrophilic material which would convey it downstream through the passageway to the main body 43 of the wick itself. Accordingly, this alternative embodiment, wherein small branches 43a of the wick material 43 extend into the air channels, very effectively removes any water droplets that might otherwise potentially block air flow in one or more of such parallel passageways.

As earlier mentioned, the fuel for the anode, hydrogen gas, is supplied by a supply conduit arrangement 29 from a rechargeable hydrogen container 27 connected thereto which leads to the passageway in the hinge 17b and then to a tubing arrangement

61 in the lid 15 which delivers H<sub>2</sub> to a similar manifold 53a that feeds the H<sub>2</sub> flow channels 54a located along the anode surface of each MEA. Hydrogen is stored in hydride form using an alloy material that will chemically absorb the hydrogen in the form of a hydride, which materials are sometimes referred to as hydrogen occlusion alloys.

5 There are a number of these alloys being marketed commercially, one of which is sold by Ergenics under the trademark Hy-Stor™. Some of them include iron-titanium-magnesium alloys, e.g. about 44 weight % iron, 55 weight % titanium and 5 weight % manganese, and Mischmetal-nickel-aluminum hydrides. The preferred metal hydride that employed is one which has a composition of about 45-50% Mn, 20-25% Ti, 10-15% Zr,  
10 10-15% V, 2-5% Fe and 1-2.5% Ni or an equivalent that readily releases hydrogen at room temperature; preferably, the alloy employed should inherently provide between about 1 and about 3 atmospheres of hydrogen at ambient temperature, i.e. about 25°C, and preferably between about 1.5 and about 3 atm.

The metal alloy material will be in particulate form so as to have a relatively large  
15 surface area per unit of mass to promote the chemical absorption and desorption of hydrogen from the alloy in order to maintain a relatively uniform vapor pressure of hydrogen within the sealed container. The uncharged particulate material should only loosely fill the container; however, when fully charged, the particles swell and will be tightly packed therein. This characteristic may be used to provide a low fuel warning as  
20 discussed hereinafter. One type of traditional hydrogen container 27a is illustrated in FIGS. 13 and 14 and includes a generally cylindrical sealed body 55 having a valve 57 and quick-disconnect connector 59 at one end. Containers of this type are well known in the art and are disclosed for example in U.S. Patent No. 5,932,365 (August 3, 1999). The container 27 will have a spring-loaded valve member 57 that is biased to the closed  
25 position and has an elongated valve stem that will be moved inwardly against the force of a spring when connection is made with the conduit network 29 that is used to deliver the hydrogen to the fuel cell unit. The specifics of the quick-disconnect connector form no part of the invention; it simply allows the container 27 to be easily replaced by disengagement of the connector 59 of a container whose hydrogen supply has been  
30 exhausted and substitution of a fresh recharged container.

As indicated above, the alloy is selected so that, at about room temperature, an absolute pressure that is within about 0.2 atmosphere of the air pressure in the channels 54b is preferably maintained throughout the conduit system 29 that includes the conduit network in the base compartment leading to a second gas passageway system in the hinge

17b that interconnects with a hydrogen conduit system in the lid compartment leading to the fuel cell unit 33. The illustrated arrangement is such that the parallel flow field channels on the anode side of each MEA will be filled with hydrogen at about this pressure, causing the hydrogen to permeate into the MEA where it comes in contact with the particulate platinum and is converted to hydrogen ion. In this embodiment, these channel dead end so there is no gas outlet on the anode side other than permeation into the electrolyte; however, in the later-described alternative embodiment, periodic venting of the hydrogen channels is carried out.

As previously indicated, a relatively low overpressure of hydrogen is preferred so that the gas pressure on the anode side will be approximately balanced by the relatively low pressure on the cathode side that results from maintaining the flow of air through the flow feed channels. A pressure of about 1.3 or 1.4 atmospheres of hydrogen may be used so as to approximately balance by the air pressure on the cathode side when a blower is employed so no specific particular reinforcement is required for the membrane electrolyte. A higher H<sub>2</sub> pressure is desirable when air of a higher pressure is supplied via a positive displacement circulator.

The fuel cell unit 33 preferably includes a plurality of subunits 63 arranged in a generally planar array inside the cover of the lid section 15. Each individual cell should generate about 0.7 V, i.e., between about 0.5 and 0.8 V, and by linking four or six cells together in series electrical connection in a stack 63, a composite voltage of about 2 to about 4.8 V is obtained. Accordingly, one subunit of 2 MEAs side-by-side (see FIG. 3) might be stacked atop another unit of 2 MEAs, with the 4 cells being electrically connected in series. FIG. 3 is diagrammatic and shows H<sub>2</sub> manifold 53a and flow channels 54a for the anode of the left-hand cell and the air manifold 53b and the flow channels 54b for the cathode of the right hand cell. Dimensions of each MEA might be about 10 cm by 10 cm, and such a cell of 100 cm<sup>2</sup> may generate over 50 amperes. Located as a generally planar array adjacent the cover of the lid, there might be two or three such subunits in a stack. The four or six individual cells would be connected together in series electrical connection. A single electrical connector would lead, in this instance, through the sliding connection in the hinge 17a to the DC/DC converter 37 which would boost the voltage to a level which is adequate to run the CPU and the motor for the blower motor 23. Methods to reduce ohmic resistance may be used as known in this art including galvanization of the outer surface of fuel cell plates, use of silver-filled glue to reduce transient resistance between field flow ribs and diffusion layers, and

mechanical compression/clamping of fuel cell plates (to provide greater contact area and smaller gaps).

The orientation of the cells in the stack is such that an anode is located facing the rear or cover wall of the lid while the cathode side of each cell faces the display screen rear surface. Preferably, there is juxtaposed with the anode side of the fuel cell subunit 5 63 a heat transfer plate 65 having a thermal conductivity at least about 50 watts/meter-Kelvin. Preferably, an aluminum or copper metal plate or a plate made of a composite material having a high thermal conductivity (e.g. containing carbon whiskers or metal shavings) is used that will pick up heat by radiation and convection from the fuel cell 10 unit and transfer it to the abutting lid surface of the laptop PC, whence it is transferred to the atmosphere through radiation and convection. Accordingly, this arrangement further assists in lowering the temperature within the lid compartment by collecting heat from the fuel cell subunits 63 and transferring it exterior of the PC case.

FIGS. 10, 11 and 12 show one embodiment of a large hydrogen container 27 in 15 the form of a fairly flat rectangular parallelepiped which is received in the complementary compartment 29 provided in the base compartment 13 of the PC. It has a quick-disconnect connector 59 and a valve 57, similar to those described above, in order to likewise connect to an inlet fitting on the hydrogen conduit system 29 in the base compartment. This H<sub>2</sub> conduit system leads to the interconnection in the hinge 17b, as 20 previously described; it also contains a second inlet 67 in the base compartment sidewall for recharging purposes which similarly includes a connector containing a normally closed valve. It is designed to mate with a connector 68, preferably a quick-disconnect connector, at the end of a flexible tube 69, as depicted in FIG. 15, leading from an electrolyzer unit 71 that will provide a stream of hydrogen gas. The connector at the end 25 of the flexible tube 69 that similarly has a normally closed valve so that the electrolyzer unit 71 can be operated, if desired with the flexible conduit 69 unattached to a PC, so as to only recharge a separate hydrogen container 27 installed therein. It also contains a standard check valve 73 to permit only outflow through the flexible line.

It has long been known that water can be separated electrolytically into oxygen 30 (O<sub>2</sub>) and hydrogen (H<sub>2</sub>). The two gases are generated as separate streams, and there have long been commercial units available for this purpose. The electrolyzer 71 used to recharge the H<sub>2</sub> containers 27 for use in the PC 11 is preferably one that employs state of the art separation technology wherein a catalyzed ion exchange membrane and closely spaced electrodes reduce the need for alkaline or acidic electrolyte. Therefore, the

electrolyzer 71 has a tank that is filled with distilled water and will be replenished with distilled or demineralized water, and water from such tank is supplied through a check valve to a cell assembly containing an ion exchange membrane. The water flows back to the storage tank, taking with it the oxygen that is created which is subsequently vented to the atmosphere through a vent provided at another location in the electrolyzer. The hydrogen, which is primarily destined for delivery to recharge a container 27, is dried to remove water using a Peltier junction and/or chemical desiccant or the like.

The electrolyzer 71 includes a pressure regulator which is used to set the desired maximum pressure of the  $H_2$  gas being delivered, e.g. at a level just slightly above the fully charged vapor pressure of the alloy chosen. This  $H_2$  pressure, when the flexible tubing 69 is connected, supplies  $H_2$  directly to the PC conduit system 29. However, the electrolyzer, as best seen in FIG. 15, also contains a door or hatch cover 75 through which a hydrogen container 27 can be installed using a similar quick-disconnect fitting as described hereinbefore. Thus, when the electrolyzer 71 is operating, it will supply  $H_2$  both through the flexible conduit 69 and to the fitting to which the  $H_2$  container 27 is internally connected to as to recharge the container that has been installed in the electrolyzer while charging and/or operating the PC. It can be seen that, using the illustrated arrangement,  $H_2$  gas will be supplied at a suitable pressure to a container installed in the electrolyzer itself and through the flexible conduit 69 to the  $H_2$  conduit system 29 in the base compartment 13 of the PC. Thus, the  $H_2$  gas being generated, in addition to recharging the container that it holds, will simultaneously provide hydrogen to operate the PC and will supply hydrogen gas to the hydrogen container 27 that is installed in the PC itself, thus recharging the PC container. The electrolyzer includes a pressure gauge which halts electrolysis when the target pressure is slightly exceeded, thus momentarily halting operation until the pressure drops just below the desired target pressure, which may occur either as a result of continuing slow absorption onto the particulate alloy material in a hydrogen container or operation of the fuel cell unit 33 for the PC. This arrangement provides a safety feature to avoid excess hydrogen generation, and the electrolyzer 71 automatically begins electrolysis operation once the pressure drops a few percent below the desired level. It has been found that, by designing a system wherein operation can be effectively carried on at a hydrogen pressure of between about 1 and 3 atmospheres, a particularly efficient arrangement is possible wherein the PC can continue to be operated while two hydrogen containers are being simultaneously recharged.

As previously mentioned, the particulate alloy that is transformed to metal hydride in the presence of hydrogen gas has a tendency to physically swell, transforming a loose bed of powder within a sealed container into a tightly packed bed, and this property can be used to provide a low fuel warning. Such hydrogen occlusion alloys have a tendency to maintain a fairly constant vapor pressure in a container until the hydride is nearly depleted, at which time there is a fairly rapid drop in pressure, shortly before hydrogen flow from the container would essentially, somewhat abruptly terminate. It has been found that, by including a sensor in the container, adequate warning of the impending depletion of hydrogen fuel can be provided. Illustrated in FIG. 11A is a container 27 wherein such a sensor 79 which is internally located. It may be a mechanical switch or a piezoelectric element and is preferably isolated in a small compartment 81 provided by a flexible membrane 83 positioned near a boundary of the container. As a result, the fully charged particulate bed of hydride material originally applies a compressive load to the piezoelectric element or closes the switch, but when the bed shrinks in size, indicating depletion of the hydride, either the pressure on the piezoelectric element will be decreased or the switch will open, thus sending a signal to the computer, that could appear in a corner of the display screen or as a lighted, separate LED in the keyboard area, indicating the fuel is nearing depletion and that it is time to change fuel cartridges.

In the alternative embodiment of the invention illustrated in FIG. 16, an arrangement is shown which provides a higher gas pressure at the MEA, both on the air side and on the hydrogen side. In this embodiment, a smaller blower 23' is provided driven by its own motor 85 to provide cooling to the CPU 21 and to the electrical circuitry 25 in the base section of the case. Because of a desire to provide a higher pressure of air at the cathodes, a positive displacement circulator 87 is provided driven by its own motor 89 to supply air through the conduit system in the hinge 17a. If desired, the same motor could be employed to run both the blower 23' and the positive displacement circulator 87, and such would be operated so that maintaining the desired downstream pressure of air from the positive displacement circulator would be predominant.

Also illustrated is a further improvement to assure orderly shutdown of the computer if the container 27' is about to be depleted of fuel, as for instance should the operator simply ignore a low fuel warning when such a sensor 79 is incorporated, or have simply stepped away from the computer with it running. In this arrangement, each fuel

container 27' is provided with a small attached reserve container 91 which is incorporated as a part of an outlet assembly 93. The reserve container 91 is connected via a three-way valve 95 in the outlet assembly 93, which valve is electrically controlled by a simple control mechanism 97 linked electrically to the CPU 25. A pressure sensor 99 is located  
5 in the hydrogen conduit system 29' leading to the hinge 17a which sends a signal to the control mechanism 97 indicative of the line  $H_2$  pressure.

In this system, when the hydride alloy material reaches a condition nearing depletion of the hydrogen, there is a fairly rapid drop in partial pressure of  $H_2$  which constitutes the gas pressure within the conduit system 29', for example, from a hydrogen  
10 partial pressure of about 2 atmospheres to a level below 1.5 atmosphere. This pressure drop is detected by the pressure sensor 99 and by the control mechanism 97 as a result of the signals from the pressure sensor. The control mechanism 97 signals the three-way valve 95 to rotate  $90^\circ$  clockwise from the position illustrated, connecting the reserve cartridge 91 to the hydrogen supply conduit system 29'. As a result, hydrogen from the  
15 reserve cartridge 91 will continue to fuel the MEA for a given period of time. At the same time, the control mechanism 97 will signal the CPU, which will then indicate that fuel depletion has occurred and that, within a preselected time period, orderly shutdown of the computer will be automatically effected if the fuel cartridge 27 is not replaced. As a result of this arrangement, whatever work may be in progress on the CPU will not be  
20 lost but will be saved as a result of shutdown in an orderly fashion and thus will be available once hydrogen supply is reestablished. During recharging, the valve 95 will be stepped once more to open all 3 conduits.

Illustrated in FIG. 17 is an alternative embodiment of a fuel cell arrangement located in the lid 15 of a two-piece case such as that previously described. The gas  
25 supply passageways are altered from the parallel sets of passageways previously illustrated, and instead a serpentine or meandering passageway arrangement is employed. As a result of this, the area needed for the manifold is reduced allowing a DC/DC converter 100 to be located in the region between the two stacks of MEAs. Moreover, by aligning the serpentine paths so that the oxygen and hydrogen supply channels are  
30 oriented perpendicular to each other, additional reinforcement is provided for the thin membrane, as there will be a pattern of regular support for the membrane on the opposite side with respect to the gas channels of either the anode or the cathode. Because of such longer passageways and the need to supply air, which contains more than 80% nitrogen, to the cathode, a positive displacement circulator 87 is employed as opposed to a simple

blower, and such will be operated to provide an inlet air pressure for example between two to three atmospheres. The illustrated oxygen supply channels 101 are in the form of four serpentine passageways, in pairs of two; all four are supplied at a central location from a manifold 103. Then passageways travel back and forth until they terminate at  
5 openings 105 leading to the wick arrangements 41a located in the side edges of the lid as previously described. By locating the discharge openings from the oxygen channels 101 at two spaced apart points, any moisture that would condense at the wick would occur at separate locations, and the wick would be able to transport the moisture toward its center, avoiding the possibility of becoming overloaded.

10 On the hydrogen side, it is felt that only two serpentine passageways 107 are needed because of the lower amount of flow of gas. As just mentioned, these serpentine H<sub>2</sub> passageways 107 are aligned vertically in FIG. 17 so as to be transverse to those supplying oxygen on the cathode side of the membrane electrolytes. Because commercial pure hydrogen can contain minute fractions of other gases that will not react  
15 and thus would tend to accumulate in the passageways, and because there is the possibility of some water from the fuel cell reaction reaching the gas stream on the anode side, it has been found that more efficient electricity production can be assured by periodically venting the hydrogen passageways 107. Accordingly, the hydrogen passageways from each anode in the cell stack on the right-hand side of the two-cell  
20 arrangement illustrated in FIG. 17 are manifolded to a valve 109 that connects to a conduit 111 discharging through an opening leading to the wick arrangement in the side edge of the lid, similar to the exit arrangement for the air passageways. The valve 109 is periodically remotely opened and closed by signals from the CPU; for example, each 15 minutes, the valve 109 might be opened for 30 seconds, which would allow the greater-  
25 than-atmospheric pressure of hydrogen in the passageways to slowly discharge to the atmosphere. The small amount of H<sub>2</sub> exit flow over this period of time would not create a potential flammability hazard. Overall, it is felt that the illustrated dual sets of serpentine passageway, with the passageways being transverse to each other, provide for more efficient MEA operation.

30 While the invention has been disclosed with regard to certain preferred embodiments which constitute the best mode presently known to the inventors, it should be understood that various modifications and changes as would be obvious to one having the ordinary skill in this art may be made without departing from the scope of the invention, which is set forth in the claims appended hereto. Although the preferred

arrangement is that shown wherein the fuel cells are located in the lid compartment behind the official display screen, if the fuel cells were made in the form of plates of less area, these plates might be stacked one atop another in a thick array or brick form that could be accommodated in the base compartment generally similar to the present-day  
5 battery pack that is used to commonly drive a laptop PC. In such an arrangement or in the present arrangement for that matter, instead of locating the hydride fuel container in the base compartment itself, an elongated hollowed-out hinge of the piano-hinge type could be provided that would accommodate one or two cylindrical fuel containers of the general type depicted in FIGS. 13 and 14. Such a container could be inserted from either  
10 or both ends of the PC hinge while the central portion of the hinge is reserved for the electrical connections between the lid and the base compartment and the gas passageways for one or more of the reactants for the PEM cell. In addition, instead of powering the PC from a single large hydride containing container, a plurality of smaller cylindrical containers of the type depicted in FIGS. 13 and 14 might be employed; such is  
15 illustrated in FIG. 6, which shows an alternative arrangement where a hydrogen conduit system 29a is depicted which would have the usual charging opening at a sidewall of the base compartment but would have an extended manifold leg that would contain four quick-disconnect connectors to which four separate smaller hydride containers could be  
20 attached. The disclosures of all patents mentioned herein are expressly incorporated herein by reference.

Particular features of the invention are emphasized in the claims that follow.

## CLAIMS:

1. A portable electronic device which is powered by a proton exchange membrane (PEM) fuel cell that produces water as a by-product of electricity generation, which device comprises

a case,

an electronic unit and a display screen in said case,

a fuel cell in said case for providing electric power which creates water as a by-product,

said case containing air entrance and exit openings to the exterior, and

a hydrophilic water transporter for transferring said by-product water away from said fuel cell, which water transporter is located along a perimeter boundary of said case,

said water transporter including a perforated outer generally tubular holder which is associated with said exit opening and a generally coaxial perforated inner tube of lesser diameter with elongated hydrophilic wick material disposed within said inner tube,

whereby said water transporter adsorbs water in the vicinity of said fuel cell and said adsorbed water is distributed along and throughout said hydrophilic wick, aiding its evaporation into air in the annular region between said perforated inner and outer tubes, and subsequently exits from said case as water vapor via said exit opening.

2. The device according to claim 1 wherein said inner tube and said outer tubular holder include generally radially extending stand-offs which maintain said generally coaxial spaced apart relationship.

3. The device according to either claim 1 or 2 wherein said elongated wick material is generally circular in cross-section and has a diameter so as to fit closely within said inner perforated tube.

4. The device according to either claim 1 or 2 wherein said porous outer holder is formed as an integral part of said case.

5. The device according to claim 4 wherein said case is a two-piece case of generally rectangular shape with said electronic unit being a CPU located in a first piece of said case and said fuel cell and said display screen are located in a second piece of said case and wherein said water transporter is formed as two separate units with one unit being located along each one of two parallel side edges of said second piece of said case.

6. The device according to claim 5 wherein said case includes air circulatory means in said first case piece and conduit means connected to said circulatory means which supplies a stream of air under pressure centrally between two side-by-side fuel cells which have anodes and cathodes so that air flows through channels past the cathodes to provide oxygen to react at said fuel cells and then transversely through said coaxial tube arrangement and finally out said exit opening.

7. The device according to claim 6 wherein said channels which extend past said cathodes are serpentine in shape, and wherein serpentine channels supply hydrogen to the anodes.

8. The device according to claim 6 wherein said elongated wick material comprises an elongated body that includes a bundle of strands of hydrophilic fibrous material.

9. The device according to claim 8 wherein individual strands from said bundle branch from said elongated body and individually extend into said parallel air flow channels so as to guard against potential water droplet blockage of an individual air flow channel.

10. A portable electronic device which is powered by a proton exchange membrane (PEM) fuel cell in combination with an electrolyzer unit for recharging a hydrogen reservoir, which combination comprises

(a) an electronic device disposed within a carrying case along with a fuel cell, a first hydrogen reservoir and a conduit arrangement interconnecting said hydrogen reservoir and said fuel cell,

said conduit arrangement includes a line leading to a recharging connector which transverses a wall of said case,

said hydrogen reservoir being detachably connected to said conduit arrangement to permit its optional removal and replacement, and

(b) an electrolyzer unit including means for generating hydrogen gas and supplying said generated gas (i) to a second hydrogen reservoir detachably connected to said electrolyzer unit and (ii) to flexible tubing for connection to said conduit

arrangement and therethrough to both said fuel cell and to said first hydrogen reservoir, whereby said electrolyzer can supply hydrogen gas to power said device while simultaneously recharging said first and second reservoirs.

11. The combination according to claim 10 wherein said first and second hydrogen reservoirs contain a mass of powder having a high surface area which powder

is an alloy including manganese, titanium, vanadium and zirconium, said alloy having the ability to chemically absorb hydrogen in hydride form.

12. The combination according to claim 11 wherein said alloy can be reversibly converted to a hydride by recharging with a supply of hydrogen gas at an absolute pressure as low as about 1.5 atmospheres at ambient temperature.

13. The combination according to claim 11 wherein said powder swells in volume when charged with hydrogen and wherein said hydrogen reservoirs are sealed containers that include a compartment closed by a flexible membrane in which a sensor is disposed, which sensor activates a signal indicating that hydrogen fuel in the container is nearing depletion.

14. The combination according to any one of claims 11 to 13 wherein said device is a PC having a two-piece hinged case and said conduit arrangement contains a passageway through a hinge of said case to said fuel cell which is in the other piece thereof from that piece containing a CPU and said first container.

15. The combination according to claim 14 wherein said hydrogen reservoirs each contain a main canister, a reserve canister and a 3-way valve connecting both to an outlet for said hydrogen reservoir, and wherein means is provided for (a) detecting a drop in hydrogen pressure from said main canister indicative of depletion of hydride in said main canister and (b) opening a valve upon such detection to supply hydrogen from said reserve canister to said outlet and said conduit arrangement and (c) instigating orderly shutdown of said CPU.

16. The combination according to claim 15 wherein said 3-way valve is automatically set during recharging to connect both said reserve canister and said main canister to said outlet to simultaneously charge both.

17. A portable personal computer (PC) which is powered by a proton exchange membrane (PEM) fuel cell that produces water as a by-product of electricity generation, which device comprises

- a two-piece case,
- a CPU in a first piece of said case,
- a display screen in a second piece of said case,
- hinge means interconnecting said two case pieces,
- a fuel cell for providing electric power which creates water as a by-product in said second piece of said case,

circulatory means residing in said first piece of said case for supplying air to said fuel cell,

said fuel cell being electrically connected to said CPU through said hinge means,

said first case piece being formed with air entrance means and said second case piece being formed with air exit means, and

passageway means extending through said hinge means and interconnecting the interiors of said two case pieces, so that air carrying heat from said CPU flows through said passageway means and then through said PEM fuel cell means, providing oxygen thereto, taking up by-product water as vapor, and carrying said water vapor exterior of said second case piece through said air exit means.

18. The portable PC according to claim 17 wherein said fuel cell means includes at least two thin flat fuel cells in a side-by-side array located behind said display screen and interconnected to one another in series electrical connection with the cathode surface of each facing the rear of said display screen and with air being supplied to flow channels extending across said cathodes from a manifold located centrally between said two fuel cells.

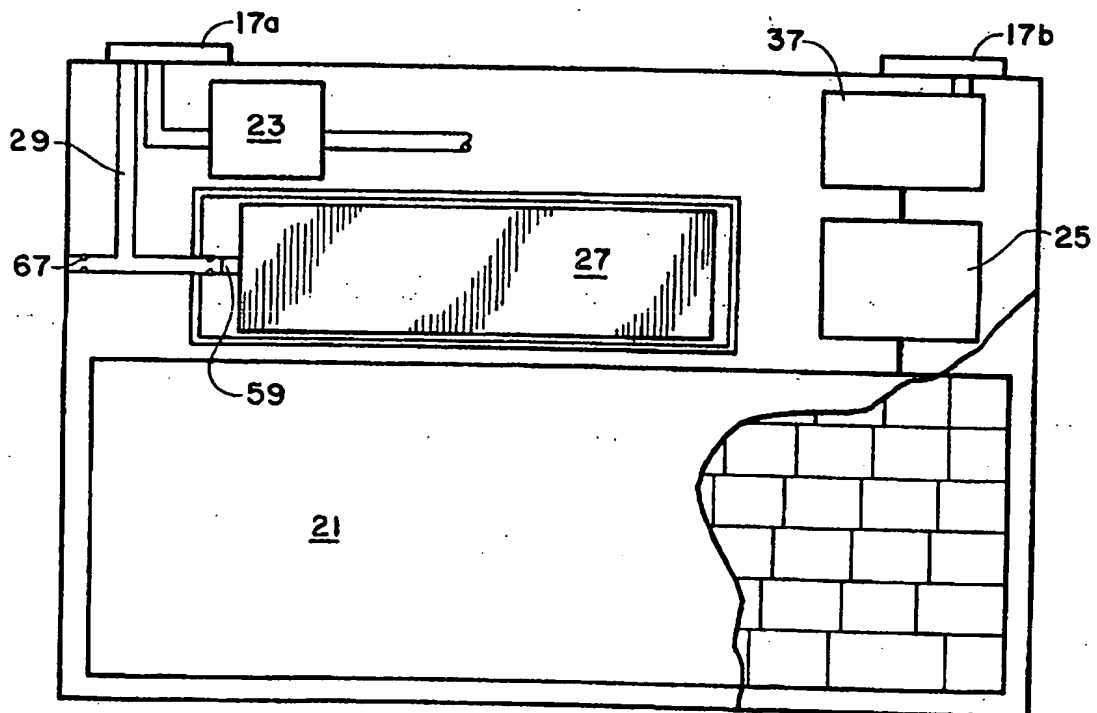
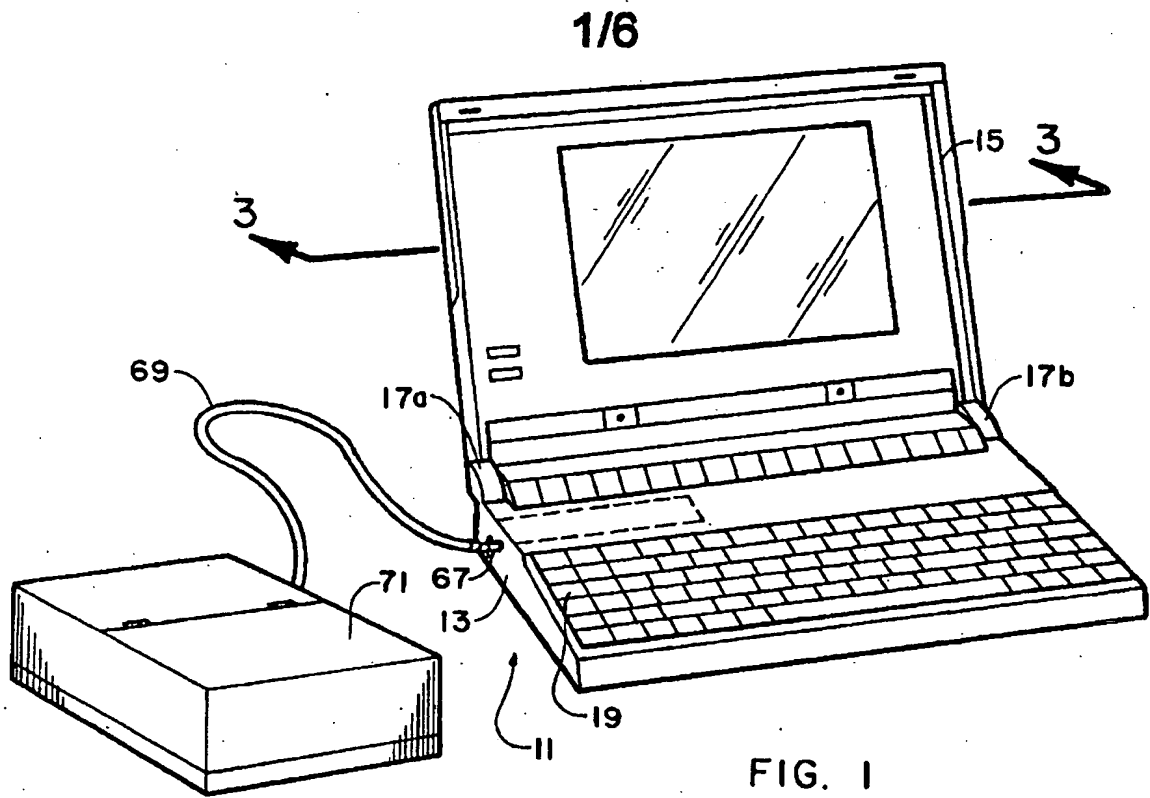
19. The portable PC according to claim 18 wherein hydrogen is supplied to a first flow channel arrangement extending across the anode which are normally closed and wherein means is provided for periodically opening said hydrogen channels to vent them to said air exit means for short periods of time equal to less than 5% of the time between said periods.

20. The portable PC according to claim 18 wherein hydrogen is supplied to a first flow channel arrangement extending across the anode and air is supplied to a second flow channel arrangement extending across the cathode on opposite surfaces of the PEM and where said first and second arrangements are aligned transverse to each other.

21. The portable PC according to claim 20 wherein said flow channel arrangements include serpentine passageways.

22. The portable PC according to any one of claims 18-21 wherein at least four fuel cells are provided in two stacks in a generally planar array and electrically connected in series and wherein said case second piece includes flat plate means having good thermal conductivity in a wall section of said case adjacent to the anode sides of said fuel cells in said plurality of stacks which plate collects heat therefrom and radiates such heat exterior of said case.

23. The portable PC according to claim 22 wherein said first case piece is a base section, said second case piece is a lid section and contains a conduit arrangement constructed so that air flowing into said lid section of said case through said passageway means flows into central manifold means located between said two stacks whence it is distributed across said cathode surfaces in flow channels.



**FIG 2**

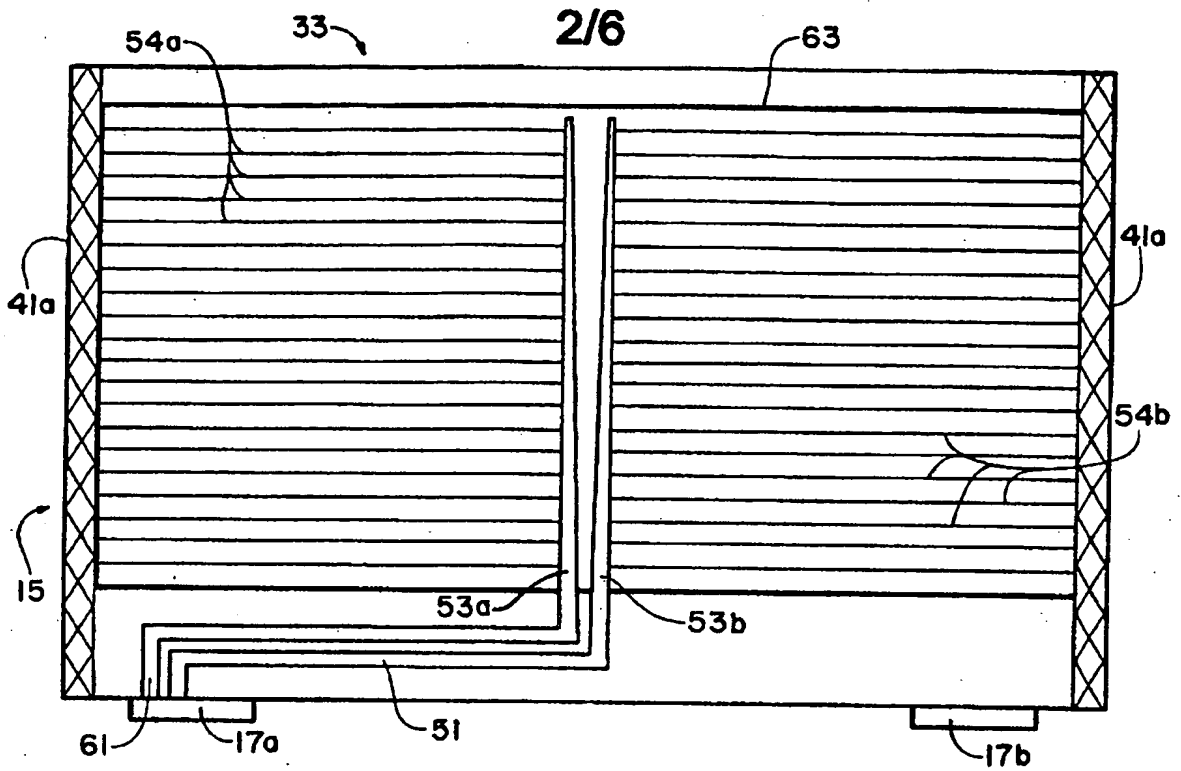


FIG. 3

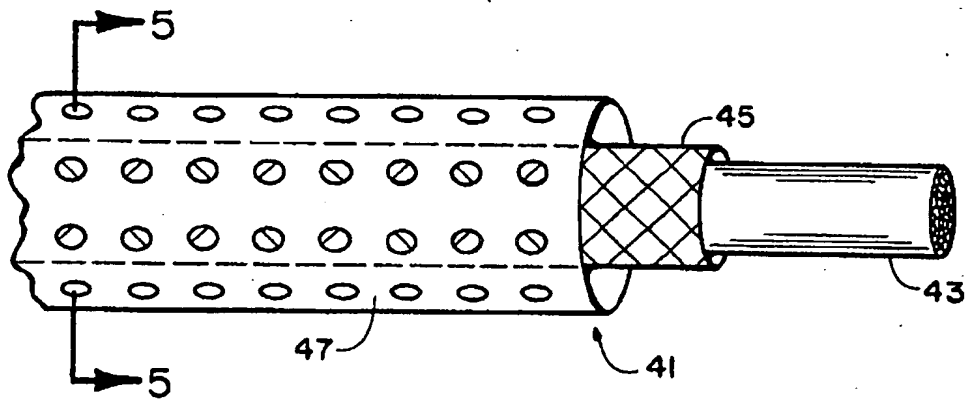


FIG. 4

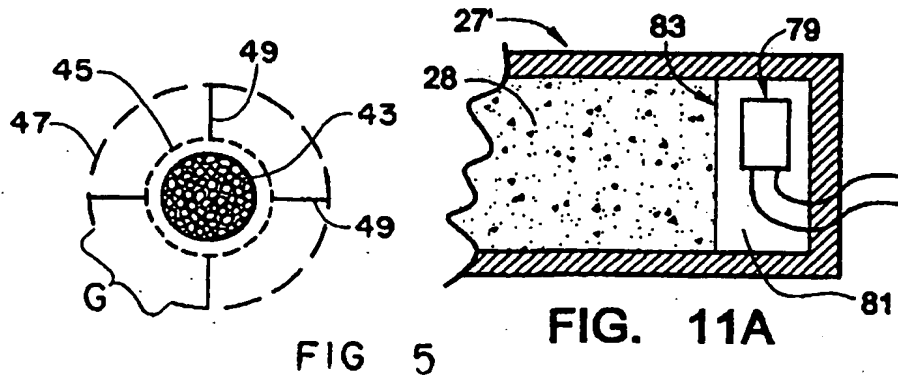


FIG. 5

FIG. 11A

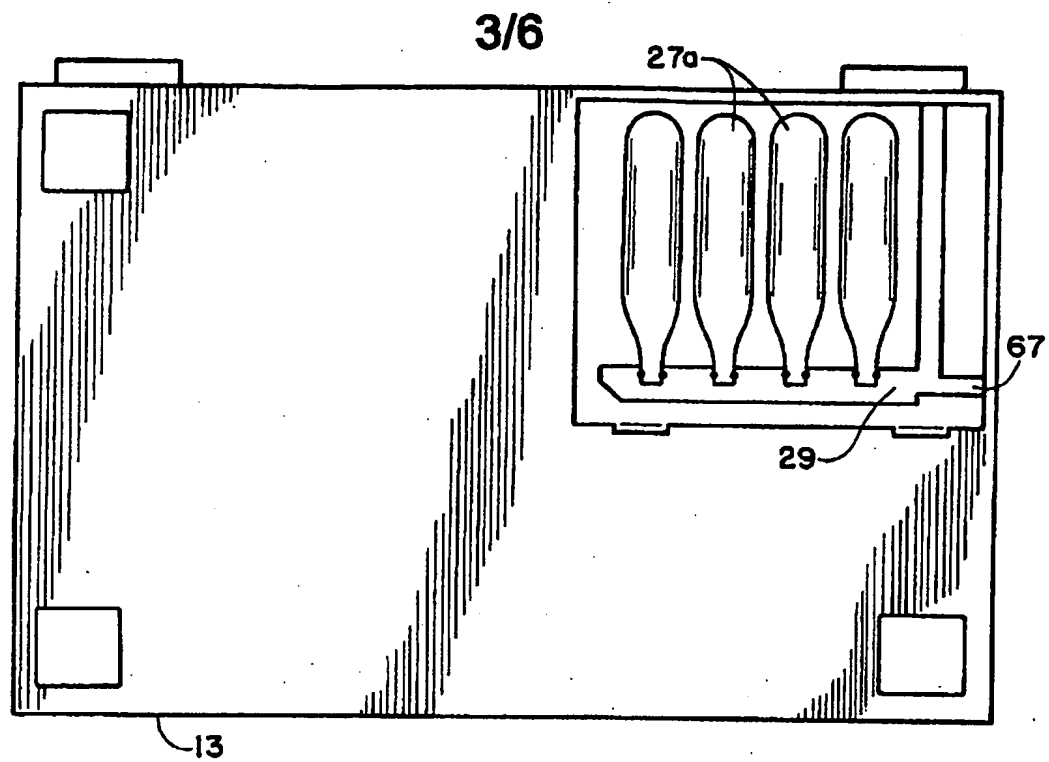


FIG. 6

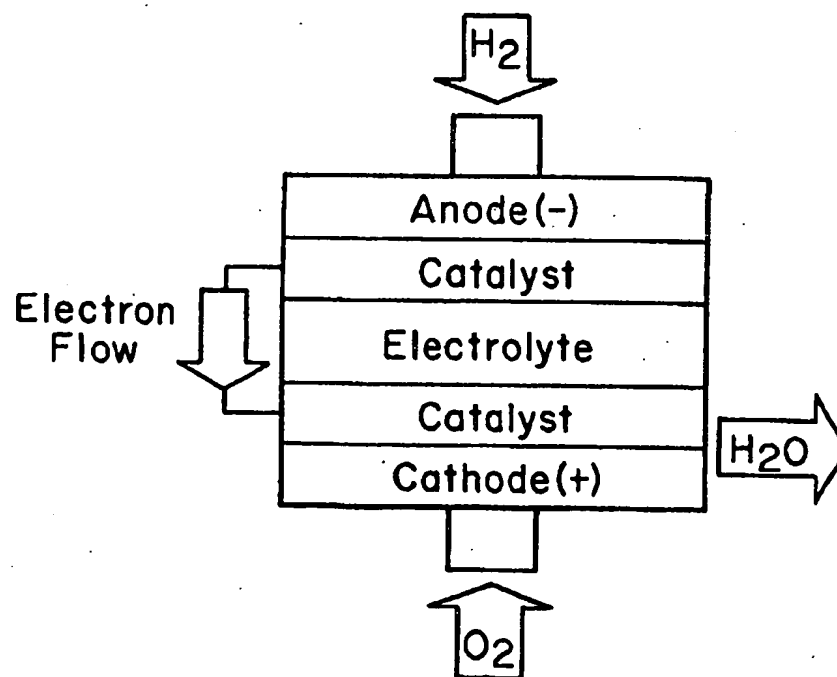


FIG 7

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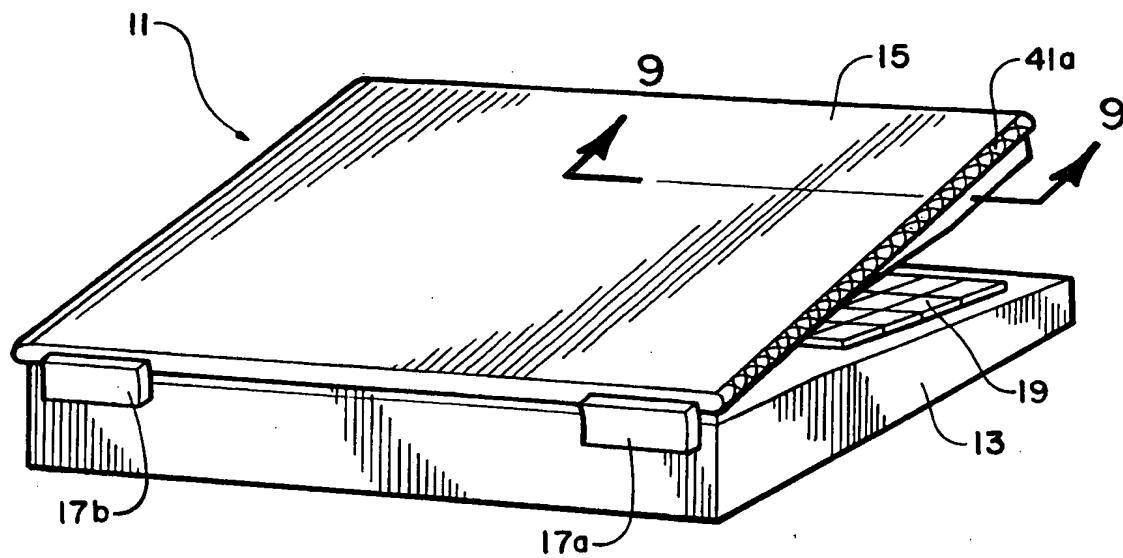


FIG. 8

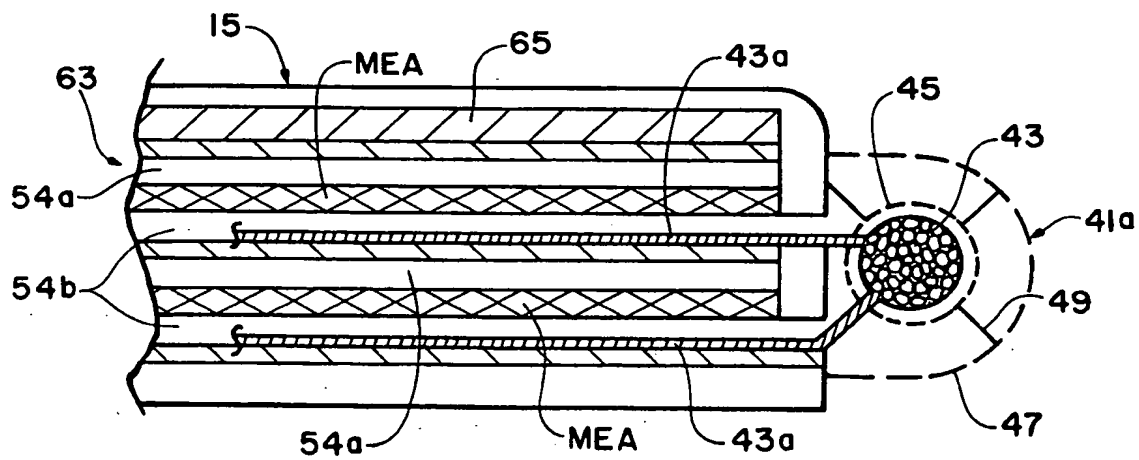


FIG. 9

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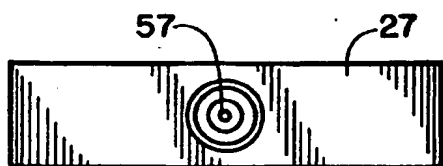


FIG. 12

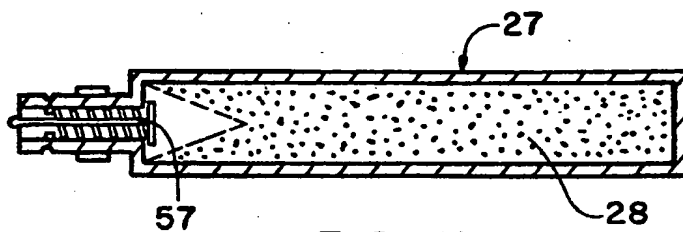


FIG. 11

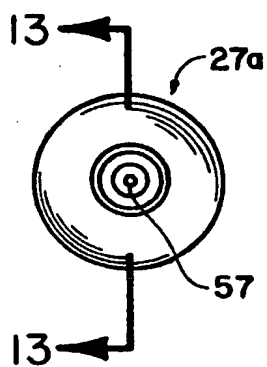


FIG. 14

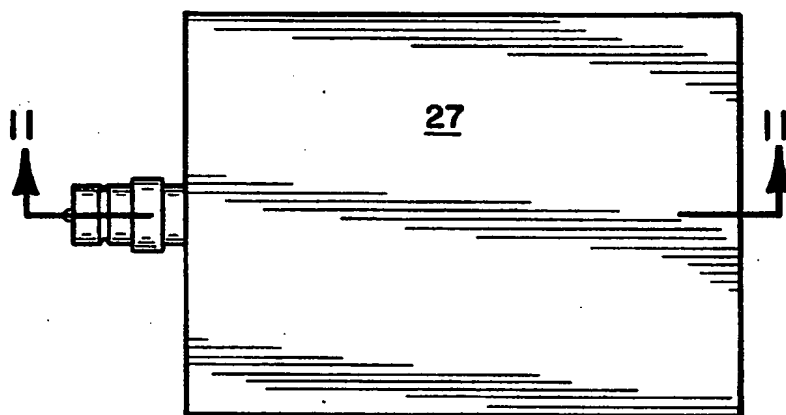


FIG. 10

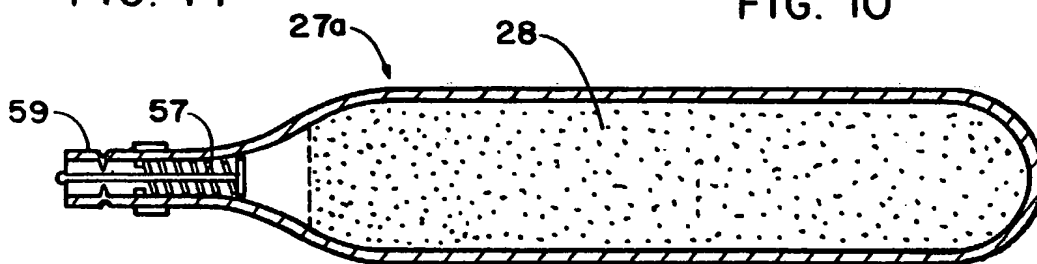


FIG. 13

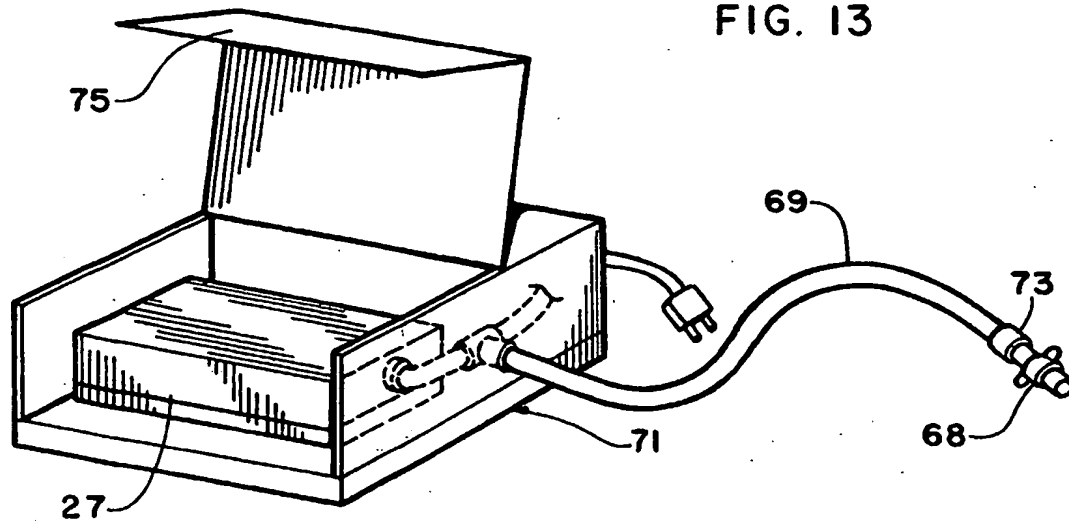
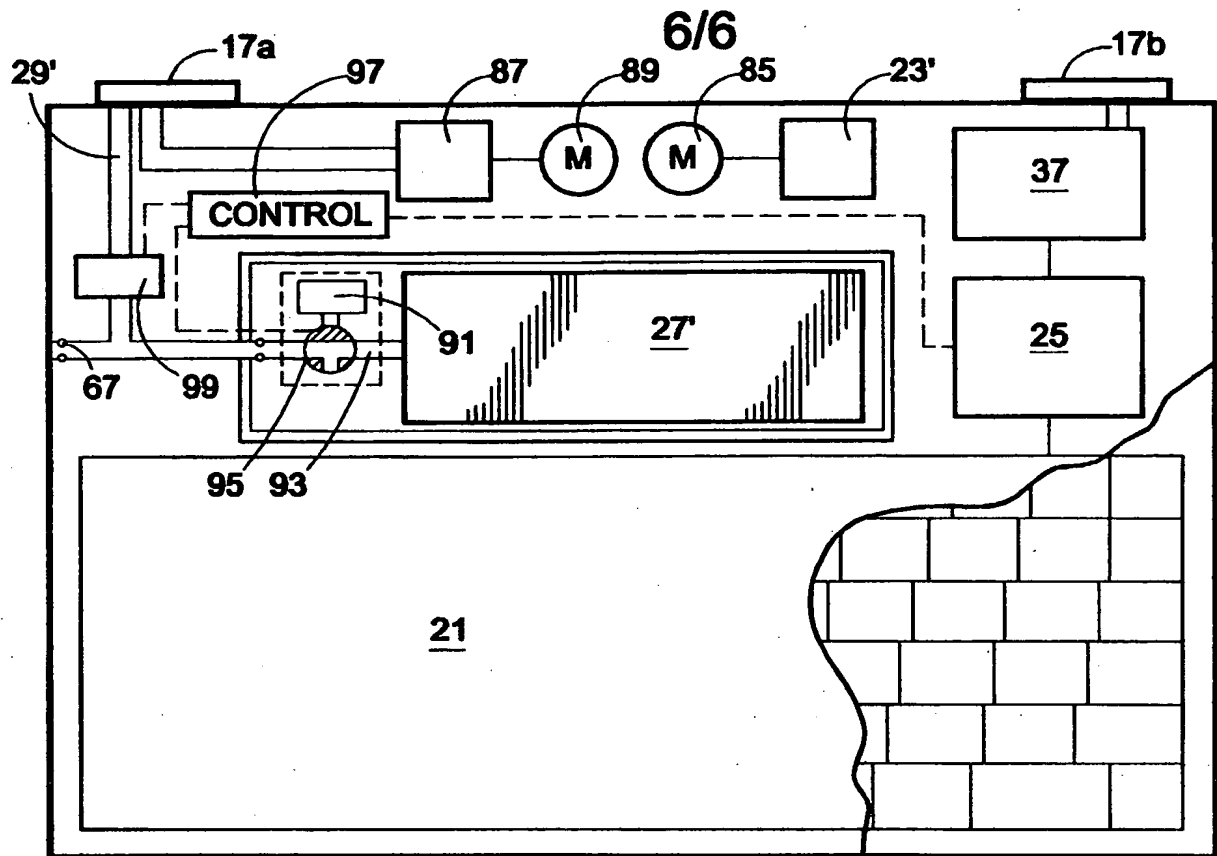
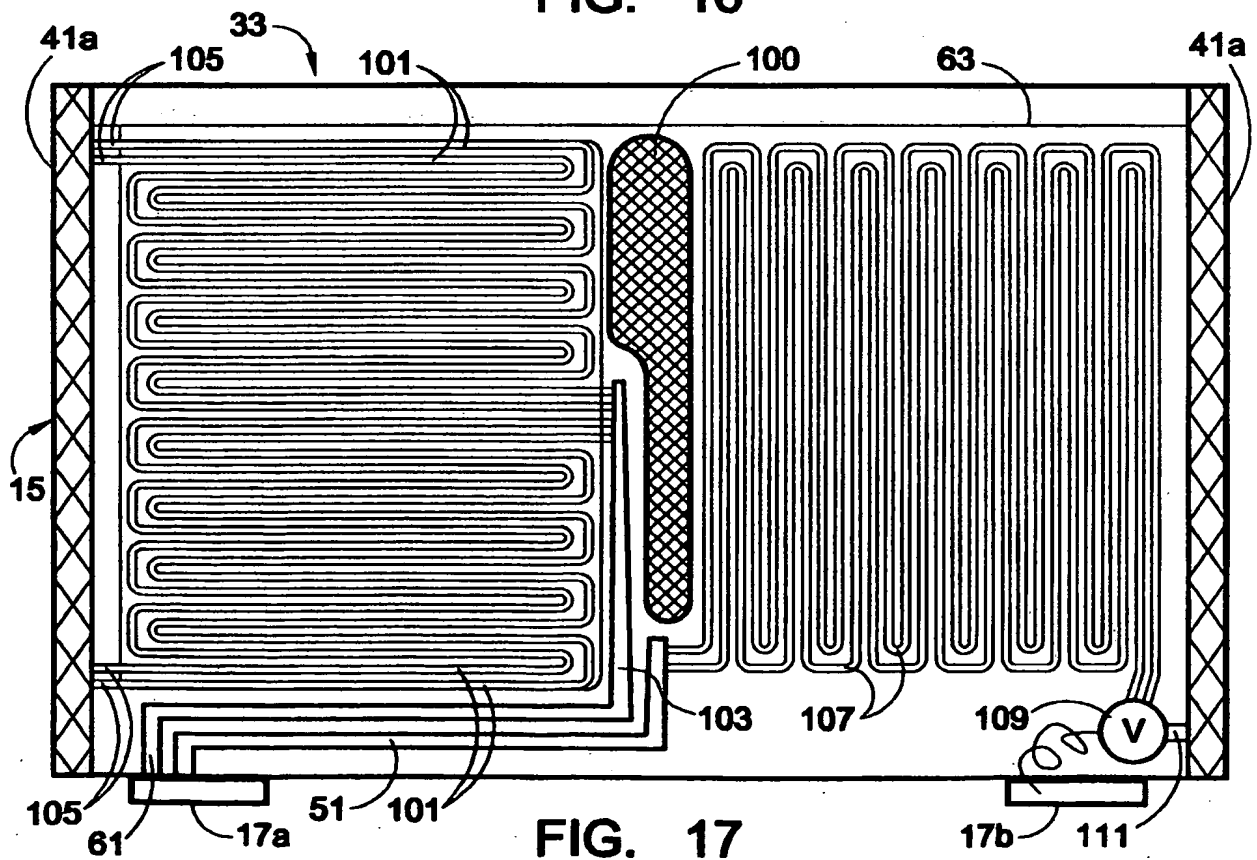


FIG. 15



**FIG. 16**



**FIG. 17**

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US01/48352

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : Please See Extra Sheet.

US CL : 429/26, 34, 38, 39; 700/286; 205/343

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 429/26, 34, 38, 39; 700/286; 205/343

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6,326,097 B1 (HOCKADAY) 04 December 2001, see entire document.	1-23
A	US 6,259,971 B1 (MITCHELL et al) 10 July 2001, see entire document.	1-23

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	"I" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier document published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"G" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

21 MAY 2002

Date of mailing of the international search report

11 JUN 2002

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Jean Proctor  
Paralegal Specialist

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US01/48352

### A. CLASSIFICATION OF SUBJECT MATTER:

IPC (7):

H01M 2/00, 2/02, 2/14, 8/04, 8/12; G05D 11/00, 17/00, 3/12, 5/00, 9/00; C25B 1/00, 3/00